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STS 62 Final Report

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1.0 Introduction

The report is organized into sections representing the phases of work performed in analyzing the STS 62 results and preparing the instrument for STS 65. Section 2 contains a brief analysis of the STS 62 data which verifies the instrument changes to resolve the STS 58 problems. Section 3 describes the results from STS 62, including the original mission plan and several minor calibration period anomalies first discovered on STS 58 and reappearing to a lesser extent on STS 62.

2.0 Resolution of STS 58 Problems

The primary purpose of the early STS 62 data analysis was to verify that the STS 58 anomalous behavior problems had been resolved. This section discusses the flight results of evaluating the previous anomalies. Reference 1 provides further details on these problems and their resolution prior to the STS 62 flight. The following operational anomalies were noted in reference 1 from the STS 58 mission:

- 1) X axis channel part failure
- 2) Loss of Reentry data due to mass memory full, non-reenter mode
- 3) Unsatisfactory Z axis C range scale factor calibrations

Review of the STS 62 data shows the following results for each of these problems:

2.1 X axis channel part failure

After the STS 58 mission, an operational amplifier failed in the X axis, apparently at sometime prior to post-mission ground tests. This failed part was replaced and the OARE instrument was retested and verified ready for the STS 62 mission. No anomalies were noted with the X axis data for STS 62. The failure mode noted for this problem was such that no data was output from the X axis. STS 62 X axis data is shown in Figure 1. As seen from this figure, X channel data is available throughout the STS 62 mission. This problem is now closed.

2.2 Loss of Reentry data due to mass memory full, non-reenter mode

This problem occurred on STS 58 after a EEPROM write error was detected. This EEPROM write error occurred when the system was in the state of mass memory full (non reenter mode) for some time. The same conditions were not stimulated on STS 62 because adaptation parameters had been selected to avoid any mass memory full condition until the completion of reentry mode. This problem remains open in that the software response under the conditions seen in STS 58 was not correct.

2.3 Z axis C range scale factor calibrations

On STS 58, investigations indicated that the Z axis C range scale factor anomaly was due to unexpectedly high signal levels during scale factor calibrations, most probably caused by calibration table jitter. As a result, the Z axis contrainment loop bandwidths were modified so that they would be less sensitive to this jitter.

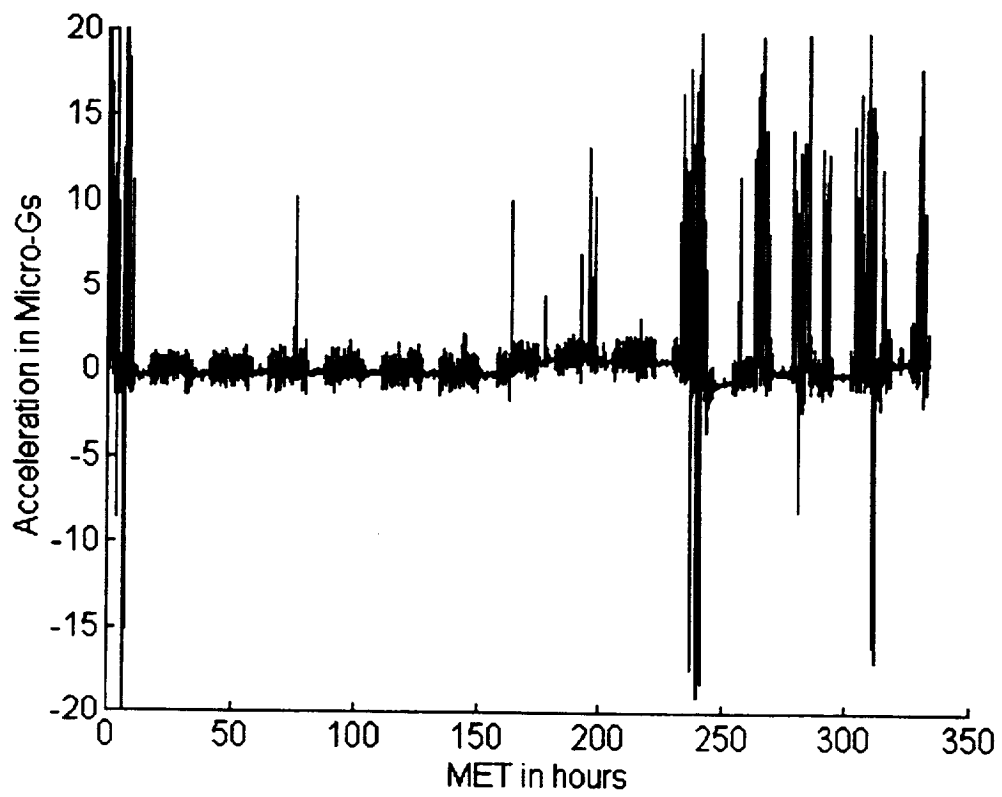
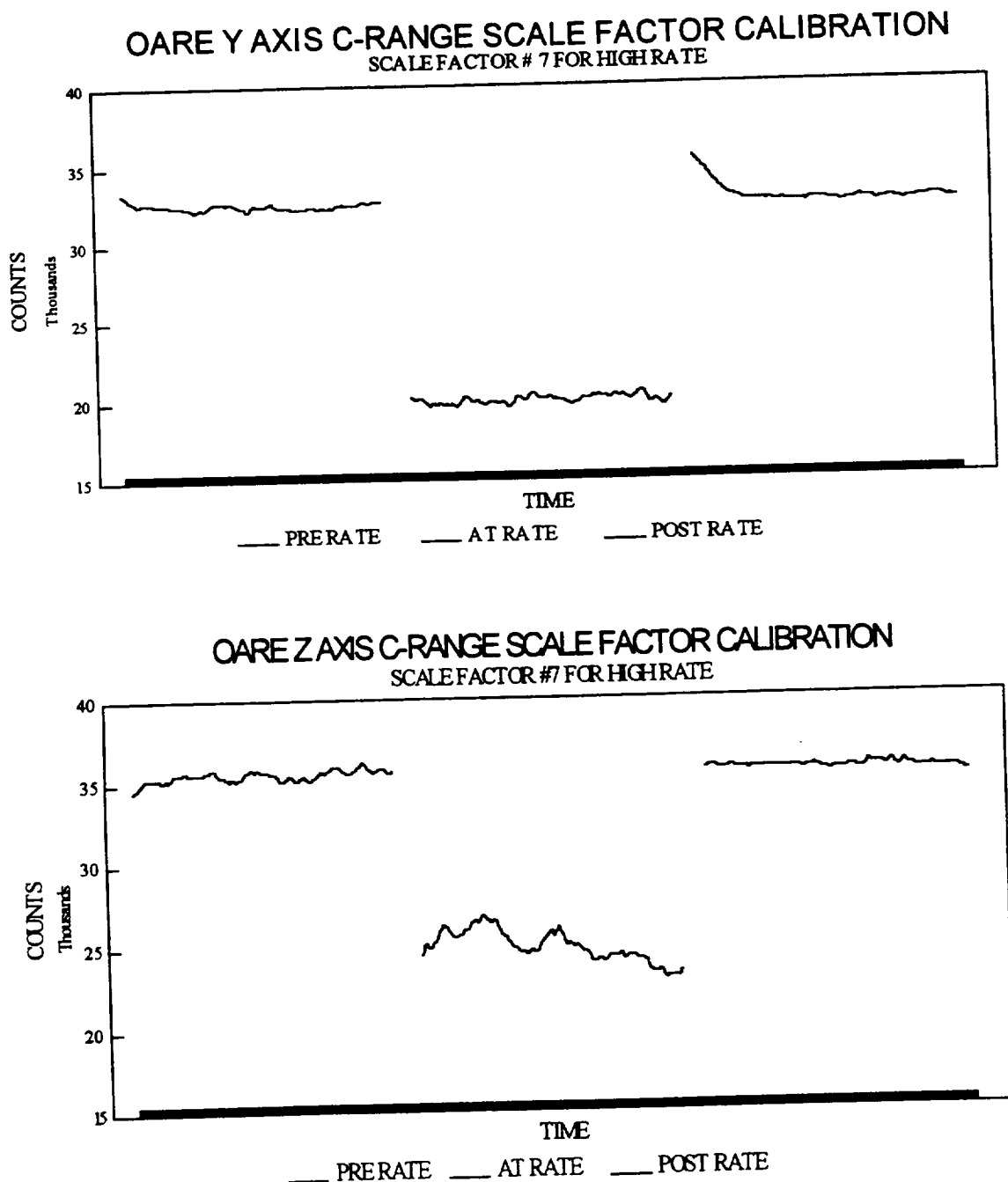


Figure 1. Shuttle X Axis STS Acceleration History

Results from STS 62 Z axis scale factor calibration indicate improved scale factor calibration data was obtained, but that the problem was not entirely corrected by the pre-STS 62 contrainment loop change. The Z axis in C range more closely tracked the table rotation, however, the response was less than expected (i.e. a correction coefficient of 1.4 was measured versus a computed coefficient of 1.1) indicating that there is still likely some effect from the table jitter. Figures 2a and 2b show the C range scale factor response for the Y and Z axes, respectively, for the example Scale Factor Calibration #7 at MET of 58.79 hours. In order to obtain the correct Z axis C range scale factor, the scale factor was calculated from the Z axis B range calibration.



Figures 2a & 2b. OARE Y and Z Axis Scale Factor Calibration Signals

3.0 STS 62 Mission Results

This section briefly describes the results from STS 62.

3.1 STS 62 Mission Plan

The STS 62 adaptation parameters anticipated a mission of up to 14 days long. The plan for bias and scale factor calibrations is shown in Figure 3. From this figure, two bias calibrations and one scale factor calibration were planned during an eight hour period of Quiet mode (planned to overlap with the crew sleep period), and three bias calibrations and one scale factor calibration were planned during the 16 hour period of Normal mode (planned to coincide with the crew awake period).

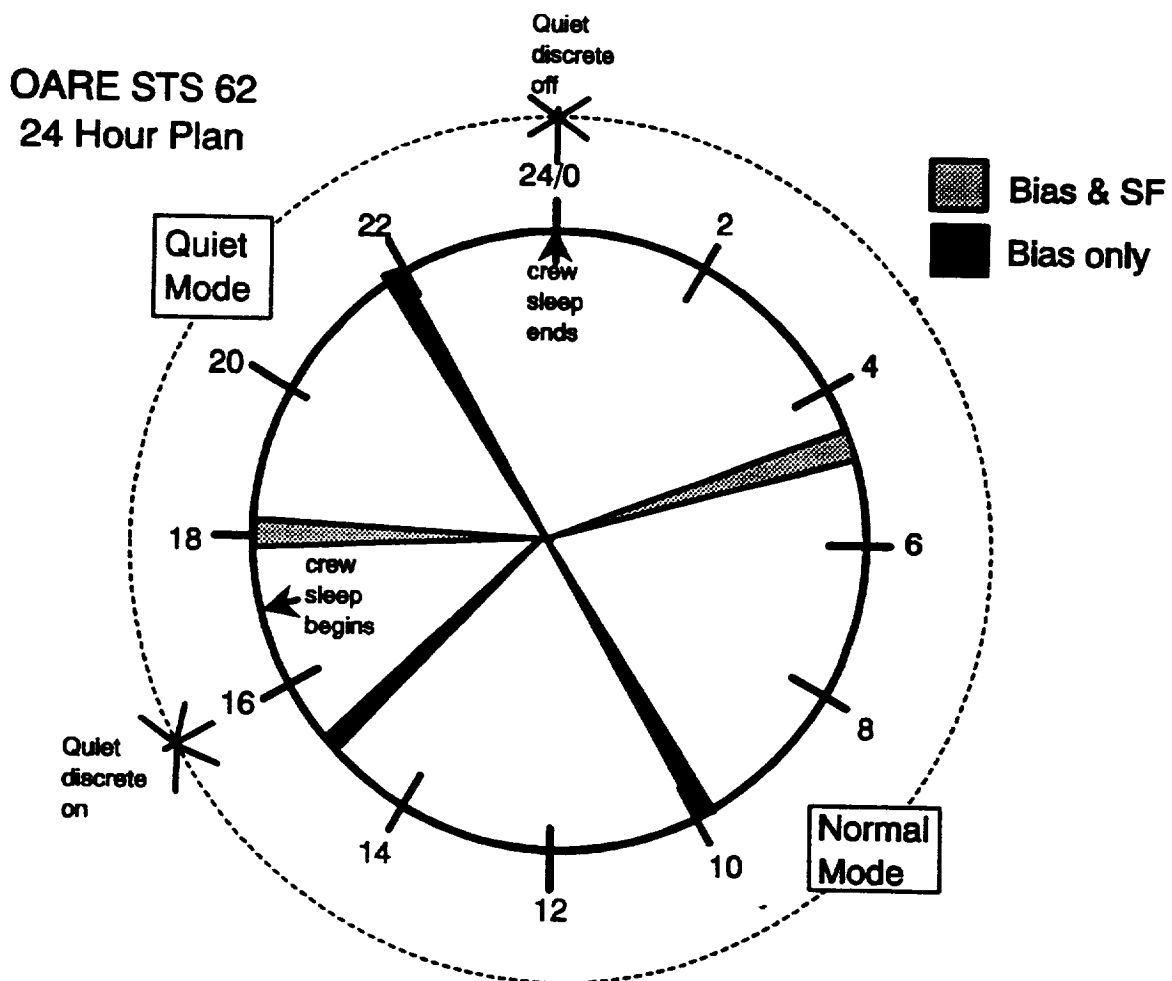


Figure 3: OARE 24 hour mission plan for STS 62

3.2 STS 62 Actual Mission Description

Launch for STS 62 was March 4, 1994. The actual length of the OARE STS 62 mission was 13d 22:51:10. Shutdown occurred in REENTER mode under the condition of "re-capture duration error" in sub-mode 4. This means that the OARE instrument continued to collect data until the Y axis signal was saturated for at least 2 minutes in the final REENTER sub-mode. This is considered normal termination of the mission, and represents correct adaptation parameter settings for the reenter file size and correct timing of the reenter discrete.

The lowest system current was 3.30 amps, recorded at 00d 11:40:03. The highest in-flight system current was 3.50 amps, recorded at several times during the mission, including 9d 12:40:16. The coldest internal temperature was recorded on the RTA gimbal 1 and 2 transducers: 10°C at 09d 10:05:40. The hottest internal temperature was recorded on the OSS base transducer: 46.2°C at 12d 18:55:29.

There were several changes to Quiet mode for crew sleep periods. The following mode changes were recorded, with the time noted:

to SAT-X	00d 00:42:30
to QUIET	00d 04:14:24
to NORMAL	00d 07:18:58
to QUIET	00d 10:30:09
to NORMAL	01d 01:44:52
to QUIET	01d 09:30:38
to NORMAL	01d 18:37:01
to QUIET	02d 08:29:53
to NORMAL	02d 17:29:00
to QUIET	03d 07:29:59
to NORMAL	03d 16:28:59
to QUIET	04d 06:30:00
to NORMAL	04d 15:29:00
to QUIET	05d 06:36:59
to NORMAL	05d 19:54:22
to QUIET	06d 05:49:59
to NORMAL	06d 14:49:59
to QUIET	07d 05:30:00
to NORMAL	07d 14:29:59
to QUIET	08d 05:29:59
to NORMAL	08d 14:30:00
to QUIET	09d 05:29:59
to NORMAL	09d 14:29:59
to SAT-X	09d 17:09:49
to SAT-X	09d 17:50:39
to QUIET	10d 05:30:00
to NORMAL	10d 14:30:00
to QUIET	11d 05:29:59
to NORMAL	11d 14:29:59
to SAT-X	11d 18:15:41
to QUIET	12d 05:29:58
to NORMAL	12d 14:29:59
to QUIET	13d 05:30:00

to NORMAL	13d 14:30:00
to REENTER	13d 21:41:21
to SAT X	13d 22:24:00
to SAT Z	13d 22:49:00
to SAT Y	13d 22:49:16
SHUTDOWN	13d 22:51:02

A total of 29 scale factor calibrations were performed in all axes and all sensor ranges. Scale factor calibration number 29 was performed in Reenter mode. Data from a total of 71 bias calibrations was saved, including three bias calibrations in Reenter mode.

From the error file, the following error conditions were noted with the time given:

13d 23:46:55 re-capture duration error

The "re-capture duration error" condition was expected.

3.4 STS 62 Data Analysis

The E²PROM flight data were recovered by accessing the OARE SPCS on Orbiter OV-102 via the GSE on 13 April 1994. This section treats the several analyses carried out on the STS-62 flight data and summarizes the significant results.

3.4.1 Bias Data Analysis

One determinate of the accuracy of the acceleration measurement is the accuracy of the bias determination of the OARE instrument as a function of time during the mission. On STS 62 a special bias calibration was made five times a day with usually two calibrations during the more quiet sleep periods. During the calibration, the OARE sensor is flipped 180 degrees and the output is measured. The sum of the outputs at 180 degrees apart divided by two is then the measured bias of the instrument. During these bias calibrations, the bias is measured for each of the three axes and for each of the three ranges on each axis.

The bias measurements indicated that the bias can be characterized by an initial transient after launch as a function of time and a small dependence upon temperature. Earlier work by Frank Marcos ["Application of the Satellite Triaxial Accelerometer Experiment to Atmospheric Density Wind Studies," AFGL-TR-0091, 2 March 1982] showed successful fits to the bias with a double exponential form. We have fitted the measured bias data with a function of the form:

$$\text{Bias} = A_1 + A_2 * e^{-(t/t_0)} + A_3 * e^{-(t/t_1)} + A_4 * T$$

where A_1 , A_2 , A_3 , A_4 , t_0 and t_1 are fitted coefficients and t is the mission elapsed time in hours and T is the instrument temperature in degrees Celsius.

In the process of measuring the bias, the OARE sensor is held in one position and 50 seconds of data are collected at 10 samples per second. These data are then processed through the trim mean filter which calculates a "best" estimate of the low frequency signal by removing the outlying data points which may be caused by various higher frequency activity such as crew activity, thruster, evaporators, pumps, vibrations, etc.; then the mean and the average deviation of the remaining

measurements from the 500 initial samples are calculated. The sensor is then rotated 180 degrees and a new set of measurements is made and processed by the trim-mean filter. The outputs are then summed and divided by two, and this is the estimate of the bias in counts for the bias calibration. A "noise" metric is also calculated which is the root-sum-of-squares of the average deviations of the measurements which were used to calculate the mean.

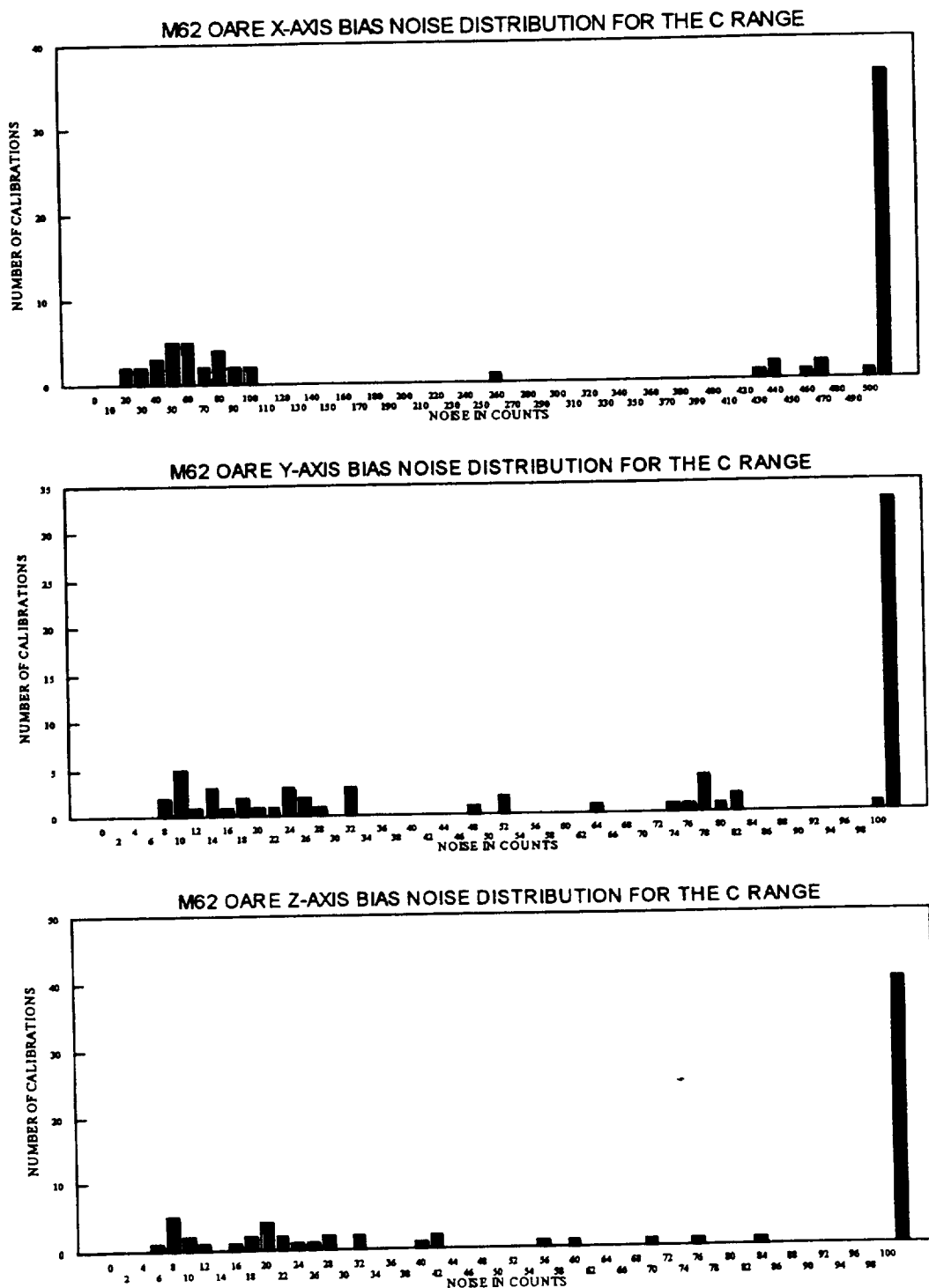


Figure 4. Noise Distributions on Each OARE AXIS in the C-Range.

In order to obtain a truly accurate measurement of the instrument bias, there should be no noise or offset contributions to the measurement of the means except the intrinsic instrument noise. However, the shuttle activity's contribution to the noise exceeds the intrinsic noise of the instrument and any changes in the average acceleration between the two bias measurements will contribute to an error in the reported bias. Thus, there may be a significant measurement error on each bias measurement. These measurement errors inherently limit the accuracy that the bias calibration can be performed.

The distributions of the noise measurements made for each axis on the C-Range are shown in Figure 4. In each case, the distributions show that the noise measurements made during the "quiet" periods of crew activity were significantly less than during normal activity periods. Because of this fact, we believe that the bias measurements made during these quiet periods are more accurate than those made during the activity periods. Also plots of the bias measurements show smaller fluctuations around the trend line for the bias measurements made during the quiet periods than for those made during the activity periods.

The bias in counts was estimated by performing a weighted least squares fit to the bias measurements where the weight was equal to the inverse of the noise-squared measured at the particular bias measurement. The functional form of the fit was the two exponential form with a linear temperature term as given above. The results of these fits are shown in Figure 5 for the X, Y, and Z axes on the C-Range. The measured and fitted bias are shown and are to read along the left axis. The residual errors between the fitted bias and the measured bias for the low noise data taken during the quiet periods is also shown and can be read along the right axis. The results of the fits and their corresponding estimates are shown in Table 1.

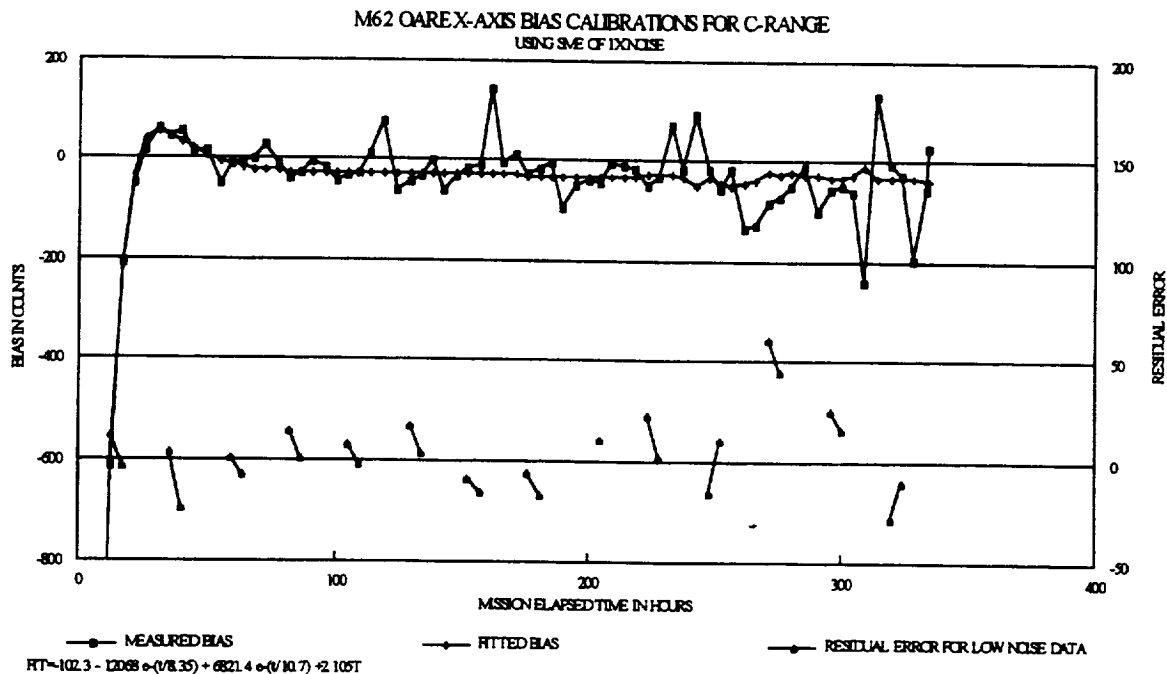


Figure 5a. OARE Bias Measurements and Estimated Biases for the X axis in C Range

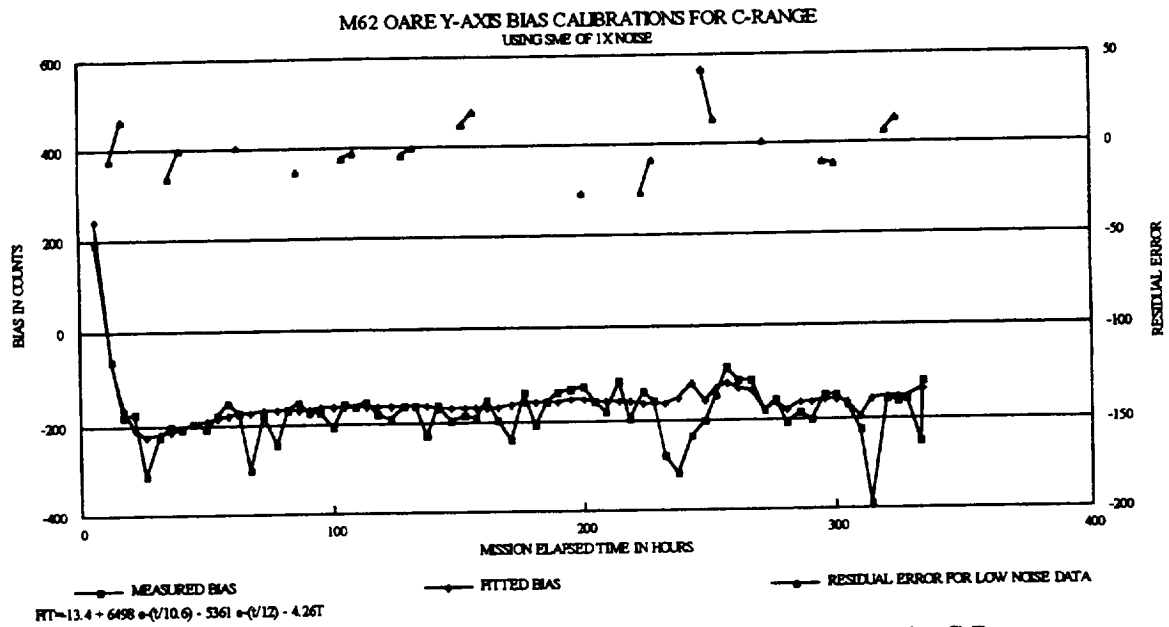


Figure 5b. OARE Bias Measurements and Estimated Biases for the Y axis in the C Range

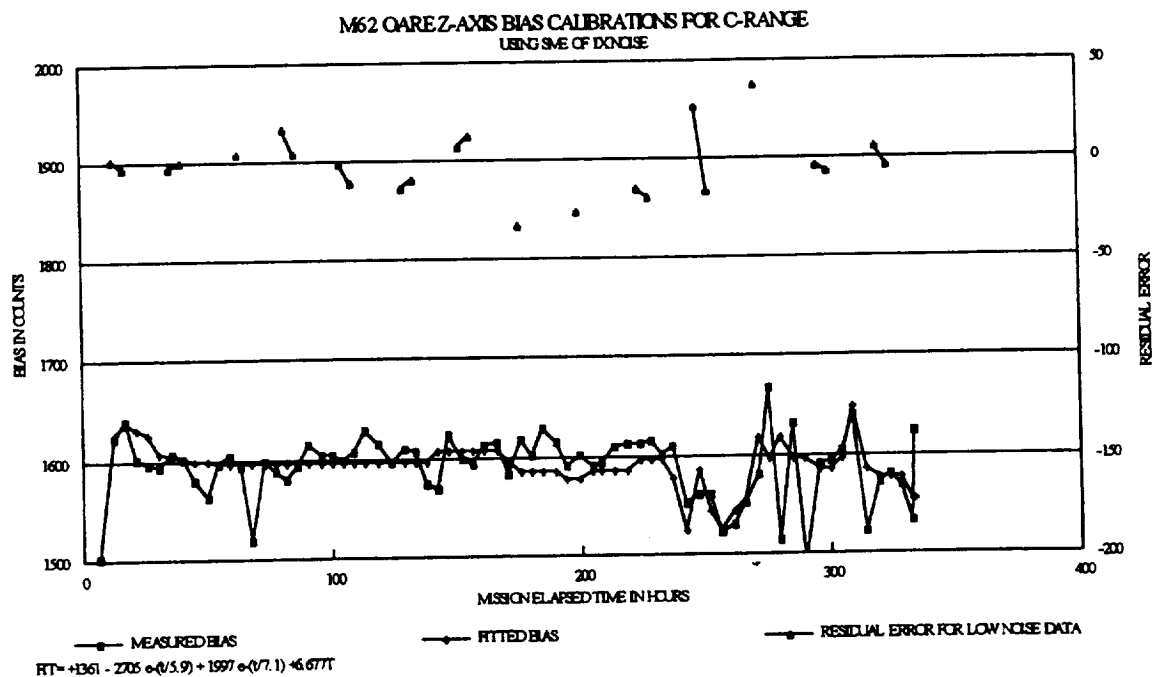


Figure 5c. OARE Bias Measurements and Estimated Biases for the Z Axis in C Range

The functional fit captures the trend of the bias measurements with no major deviations over long periods of time as shown in Figure 5; this would indicate that the functional form of the fit is

generally adequate. The differences between the fit or estimate of bias and the measurement bias are believed largely to be due to the inherent measurement errors in the bias calibration. The differences are generally much less for the bias measurements made during the quiet periods as shown both in Figure 5 and in Table 1 where the standard deviation of the fitted minus the measured data is shown for both the low-noise data obtained during the quiet periods and for all periods. An upper limit on the error in the bias calibration can be estimated from the standard deviation of the fitted minus the measured bias during the quiet periods. These standard deviations on the C-Range were about 19 counts and 15 counts for the X or (Y or Z) axes, respectively. These correspond to approximately 60 and 70 nano-g's, respectively. We believe the accuracy of the bias calibration is better than this and consistent with the OARE requirement of accuracy of 20 nano-g's over extended periods of time. Much of the contribution to these differences is due to the inherent measurement error in the bias calibration. The noise and possible non-constant accelerations generated by the on-board systems and the crew result in inherent bias measurement errors which are difficult to quantify from the e-prom data alone.

TABLE 1. M62 BIAS FIT ANALYSIS			
OARE X-AXIS			
RANGE	C	B	A
FITTED CONSTANT A1	-102.246	-24.009	17.732
FITTED CONSTANT A2	-12068.228	-726.668	-59.257
FITTED CONSTANT A3	6821.412	165.192	15.513
FITTED CONSTANT A4	2.105	0.8122	0.1258
FITTED CONSTANT σ_0	8.35	7.15	5.5
FITTED CONSTANT σ_1	10.7	15	70.5
WEIGHTED SUM-OF-SQUARES OF FIT	4.268	4.559	8.106
STANDARD DEV OF FITTED-MEASURED FOR LOW NOISE DATA	19.36	2.54	0.684
STANDARD DEVIATION OF FITTED-MEASURED FOR ALL DATA	59.68	7.77	1.159
R-SQUARED OF FIT	0.962	0.951	0.998
OARE Y-AXIS			
RANGE	C	B	A
FITTED CONSTANT A1	-13.414	21.657	32.513
FITTED CONSTANT A2	6498.086	1753.571	35.636
FITTED CONSTANT A3	-5360.907	-1633.647	-8.539
FITTED CONSTANT A4	-4.2617	-1.027	-1.077
FITTED CONSTANT σ_0	10.6	9.5	5.5
FITTED CONSTANT σ_1	12	9.9	9.5
WEIGHTED SUM-OF-SQUARES OF FIT	56.63	3.467	6.98
STANDARD DEV OF FITTED-MEASURED FOR LOW NOISE DATA	15.23	0.77	0.51
STANDARD DEVIATION OF FITTED-MEASURED FOR ALL DATA	49.74	3.46	4.63
R-SQUARED OF FIT	0.976	0.994	0.956
OARE Z-AXIS			
RANGE	C	B	A
FITTED CONSTANT A1	1361.006	213.503	170.011
FITTED CONSTANT A2	-2704.948	-261.24	-18.082
FITTED CONSTANT A3	1997.198	224.111	14.264
FITTED CONSTANT A4	6.677	0.7088	0.3015
FITTED CONSTANT σ_0	5.9	6.7	6.8
FITTED CONSTANT σ_1	7.1	7.5	9
WEIGHTED SUM-OF-SQUARES OF FIT	44.033	1.36	3.634
STANDARD DEV OF FITTED-MEASURED FOR LOW NOISE DATA	15.4	1.116	0.493
STANDARD DEVIATION OF FITTED-MEASURED FOR ALL DATA	30.31	1.933	1.341
R-SQUARED OF FIT	1.000	1.000	1.000

In order to improve the accuracy of the bias estimates or to demonstrate the projected accuracy, a detailed analysis of the data underlying each bias calibration would need to be undertaken. This would involve looking at the detailed 1000 measurements made during each bias calibration and recorded on the Payload Bay Tape Recorder. In addition, one would wish to examine the activity taking place on the Shuttle by examining data from the Calibrated Ancillary System Tapes. Through detailed analysis of these sources, one could better estimate the quality of each bias measurement and determine if they were likely to be contaminated by exogenous activity about the shuttle. By removing the corrupted data using these sources, one could obtain a more accurate estimate of the bias.

3.4.2 Scale Factor Data Analysis

Scale factor measurements are made by passing a known, non zero signal through the sensor and electronics for each channel and each range. These measurements may be contaminated by noise in the external environment or internal noise in several forms.

For OARE, the method of scale factor calibration involves rotating the Motor/Table Subsystem (sometimes called "the table") at a known angular rate with a fixed sensor to center-of-rotation offset. The known signal is thus the controlled centripetal acceleration. While collecting scale factor data, the sensor also experiences a bias (assumed fixed) and is exposed to an external signal. Data collected before and after the scale factor slew assists in removing the bias and external signal effect.

The basic scale factor measurement model is shown in Figure 6.

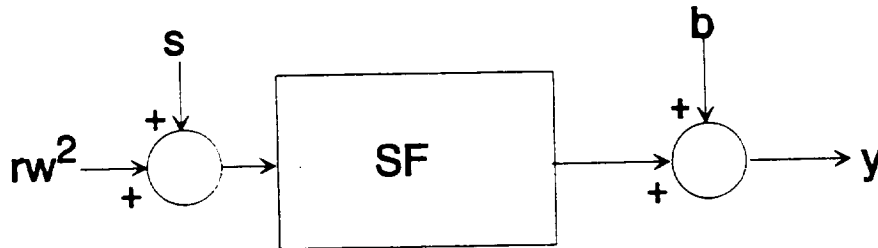


Figure 6: Scale Factor Measurement Model

From this model, the k^{th} measurement y_k is given by:

$$y_k = (r\omega^2 + s_k) / SF_A + b_k$$

where s_k is the external signal at the k^{th} measurement time and b_k is the internal bias at the k^{th} measurement time. We assume that ω is constant throughout the slew. We will also assume that s_k contains two components: (i) a signal which is fixed with respect to the MTS base throughout the slew and (ii) a noise input with zero mean. To eliminate noise, consider averages of the measurements over the data set (with length n):

$$\bar{y} = (r\omega^2 + \frac{1}{n} \sum_{k=1}^n s_k) / SF_A + \bar{b}$$

where $(\bar{})$ is the average value of () .

From this equation we can find the actual scale factor SF_A . Here, \bar{y} is the average of the measurements and $r\omega^2$ is known. The remaining unknown, \bar{s}_k , is a combination of the external

signal and noise. This is related to the midpoint measurement. During the slew, the sensor records varying magnitudes of the external signal. The bias and centripetal acceleration, however, remain fixed in magnitude. If the measurements are centered around the midpoint, the midpoint measurement can be used to estimate this external signal and remove it from the scale factor equation. It is not hard to show that the influence that the external signal and bias have on the scale factor measurements is related to the sinc function ($\sin(x)/x$) of the angular travel. The actual scale factor can then be found from:

$$1/SF_A = \frac{\bar{y} - MP(\sin(\delta)/\delta) - (1 - (\sin(\delta)/\delta))\bar{b}}{r\omega^2}$$

The scale factor correction $SF_C = SF_A / SF_N$, where SF_N is the nominal scale factor.

Scale factor corrections were calculated for all three OARE axes and the three ranges. The results are shown in Table 2.

Table 2. Scale Factor Correction Factors for M62 OARE Axes and Ranges

AXIS	RANGE	VALUE
X	A	1.01
X	B	1.01
X	C	1.01
Y	A	1.136
Y	B	1.136
Y	C	1.136
Z	A	1.10
Z	B	1.124
Z	C	1.124*

*This Scale Factor Correction was computed from the B range measurement.

3.4.3 Final Orbiter Body Axis Results

The acceleration measured by OARE in the Shuttle Body Axes coordinate system (X- toward nose, Y-toward the right wing, Z-down through the belly) are shown in Figures 7 through 14 for representative time periods. Figures 1, 7, and 8 show the acceleration during the whole mission. Figures 9 thru 14 show the acceleration for shorter periods of time.

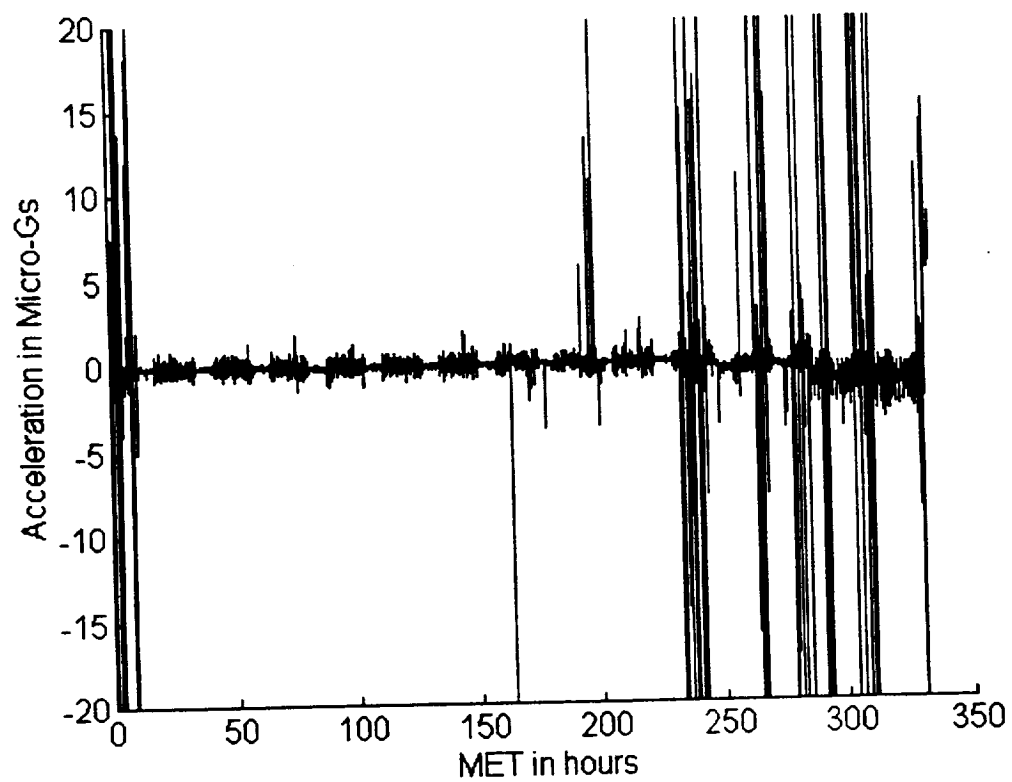


Figure 7. Shuttle Y Axis STS 62 Acceleration History

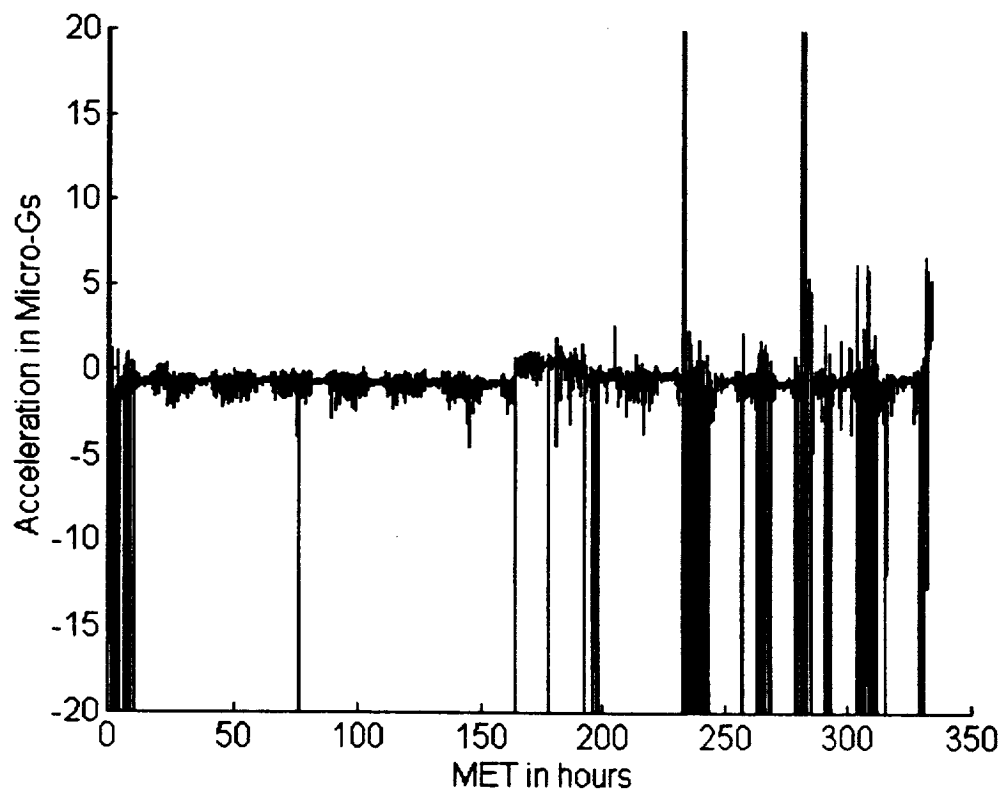


Figure 8. Shuttle Z Axis STS 62 Acceleration History

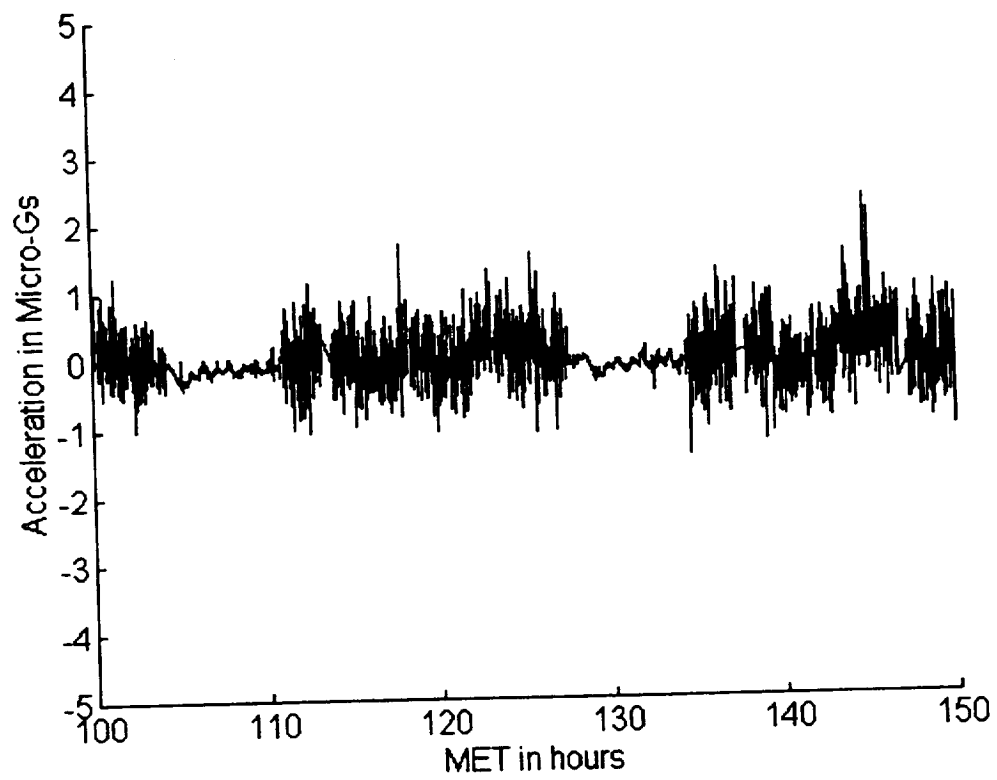


Figure 9. Shuttle X Axis STS 62 Acceleration History

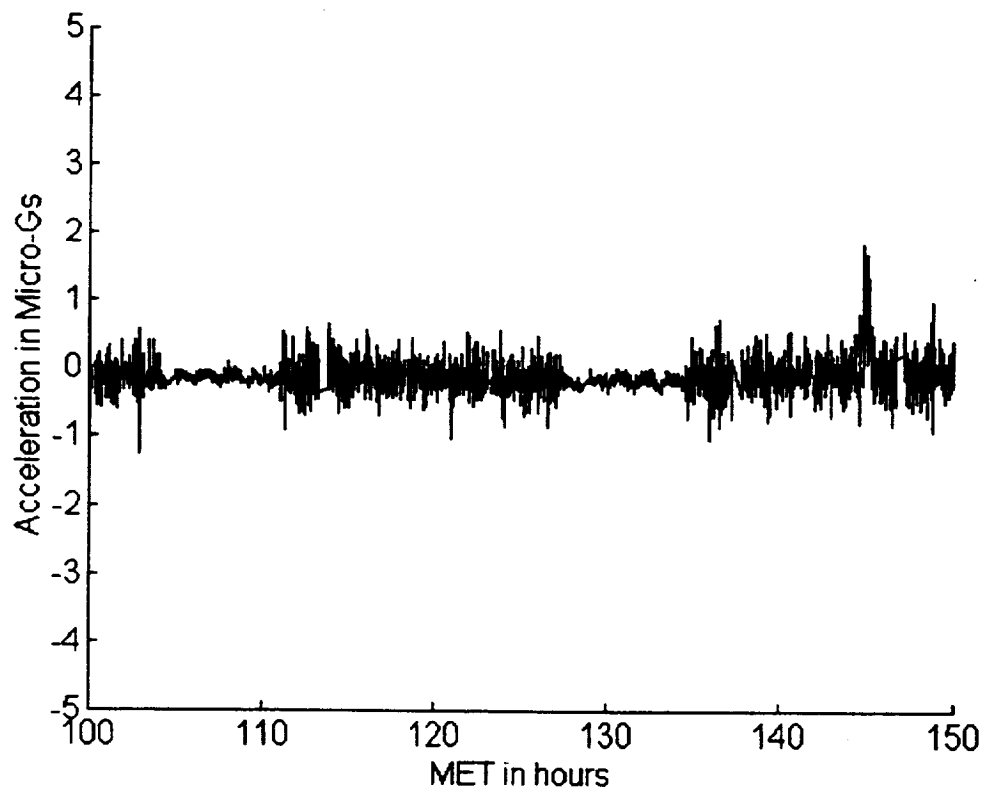


Figure 10. Shuttle Y Axis STS 62 Acceleration History

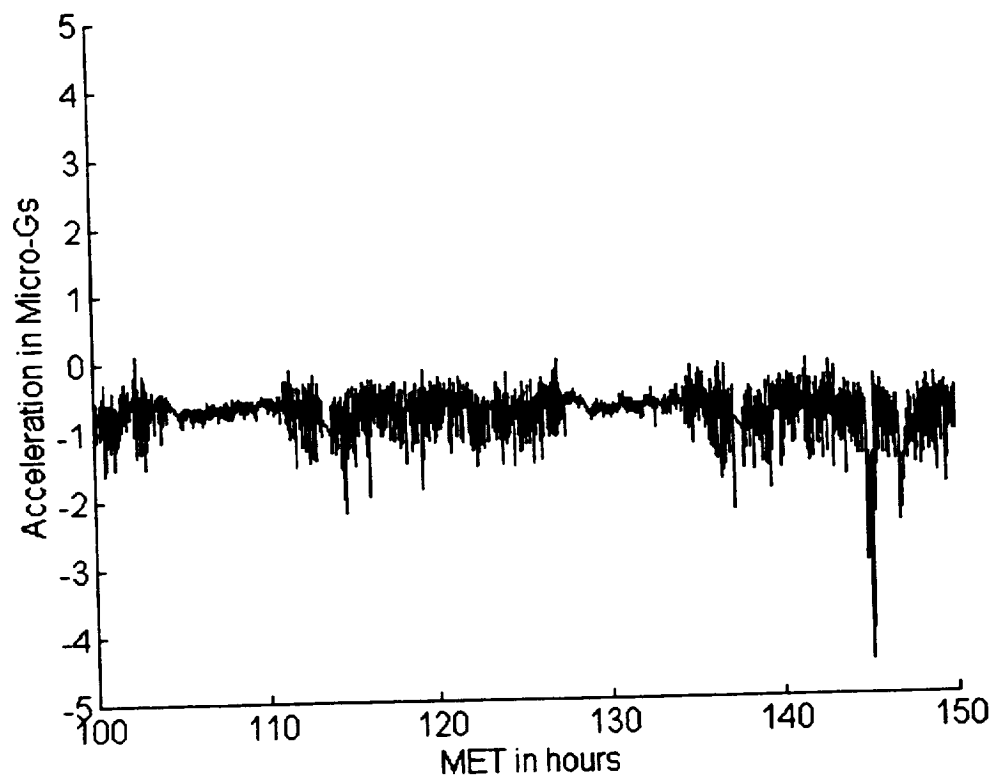


Figure 11. Shuttle Z Axis STS 62 Acceleration History

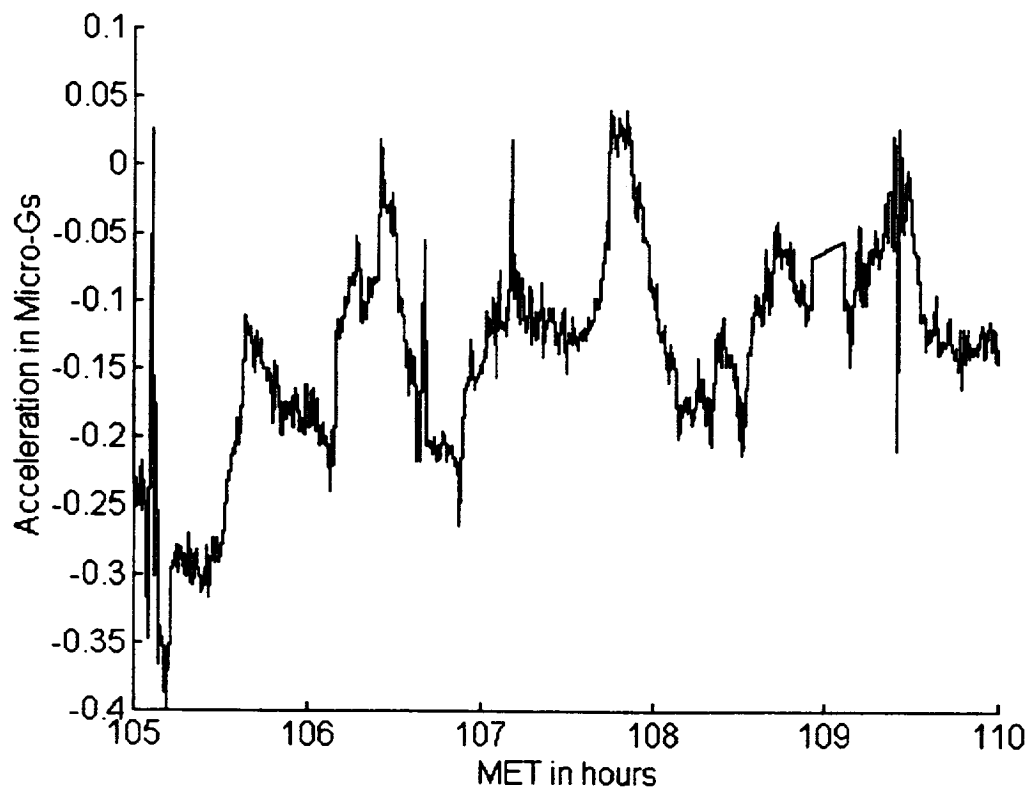


Figure 12. Shuttle X Axis STS 62 Acceleration History

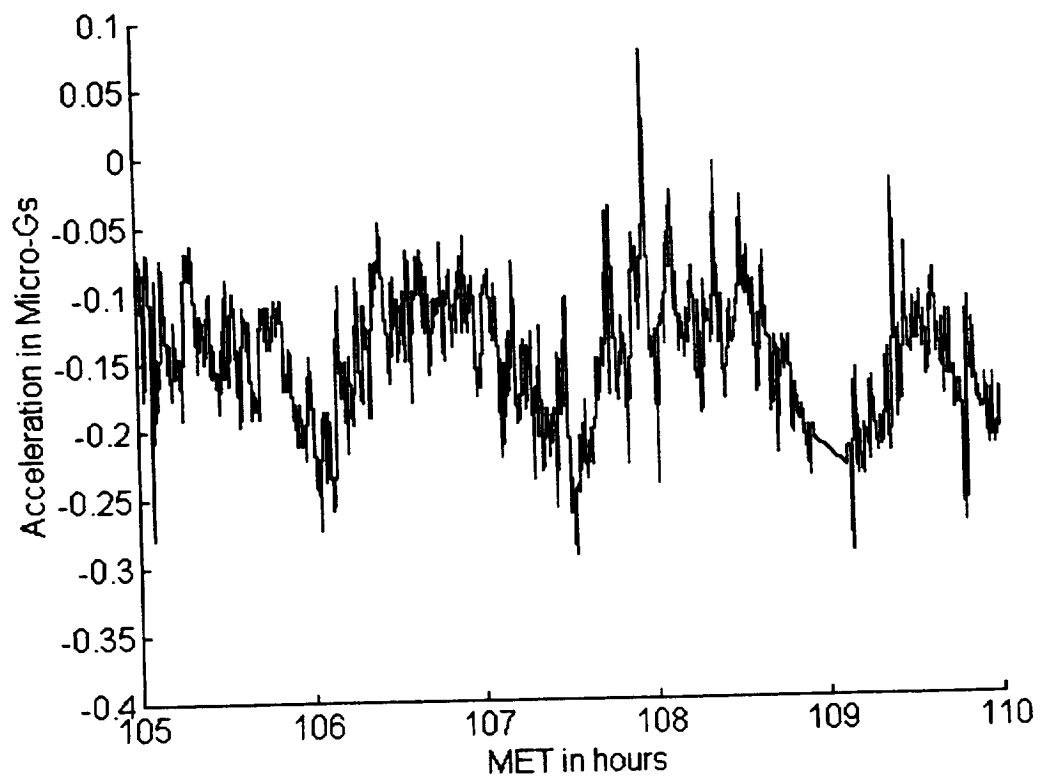


Figure 13. Shuttle Y Axis STS 62 Acceleration History

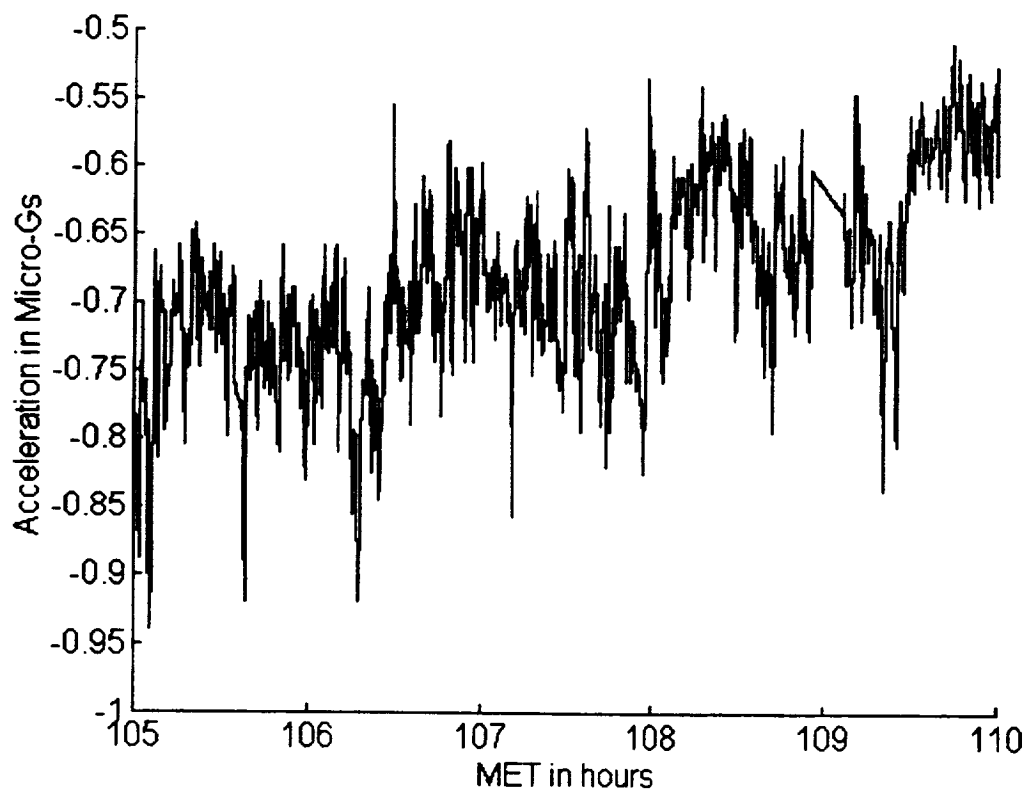


Figure 12. Shuttle Z Axis STS 62 Acceleration History

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3.5 STS 62 Anomalous Performance

OARE's performance was similar to that of STS-58. Although the Z-axis scale factor calibration improved on the C-range, the measurements were still affected by jitter to a small degree. Also, the OARE instrument in the C-range continued to show the characteristics of an "electronic bias shift" first noted in STS-58 [4]. The electronic bias shift manifested itself with small changes in the pre and post rate levels during the scale factor calibration on the Z axis in the C-range. The electronic bias appeared smaller than that on STS-58--presumably as a result of the change in the constraintment loop bandwidth changes. This electronic bias shift was not apparent in the bias calibrations and appears to be an artifact that occurs only during the scale factor calibration period and, hence, does not affect the Z-axis data collection.

The scale factor calibration measurements were nearly identical to those measured on STS-58 using the rotary table assembly (RTA). However, these in-flight scale factors differed from the ground calibration factors by approximately 14% on the Y and Z axes and by about 2% on the X axis. The RTA in-flight scale factor measurements also were verified by Orbiter body axis rotation maneuvers on STS 58 and, hence, have a high confidence level. Accordingly, the measured scale factor correction coefficients have been applied to the delivered STS 62 corrected data file.

References:

- 1) OARE Technical Report #144: STS 58 Problem Resolution Report
- 2) "Preliminary OARE Absolute Acceleration Measurements on STS 50," NASA TM 107724, R.C. Blanchard, J.Y. Nicholson, J.R. Ritter, February 1993
- 3) "Comparison of OARE Ground and In-Flight Bias Calibrations," AIAA 94-0436, presented at AIAA 32nd Aerospace Sciences Meeting and Exhibit, January 1994, P. McNally, R. Blanchard
- 4) "OARE Flight Maneuvers and Calibration Measurements on STS-58," NASA TM-109093, R.C. Blanchard, J.Y. Nicholson, J.R. Ritter, K.T. Larman, April 1994